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DYNAMIC TECHNIQUES FOR DETECTING AND TRACING TUNNEL COMPLEXES

by

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The purpose of this investigation was to determine the feasibility of using various types of dynamic test techniques to detect and trace tunnel complexes. The terrain in the vicinity of the tunnels was flat to slightly rolling with pine tree forests. The predominant soil in the area was red clay. During the testing there was continuous rainfall accompanied by occasional high winds. The types of tests conducted were: vibratory tests, drop hammer tests, seismic tests, and acoustic tests. It was concluded that:

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ABSTRACT: (Continued).

(1) Vibratory tests with a low power source were inconclusive for detection purposes;

(2) Drop hammer tests did not release enough energy to cause reverberation of an underground cavity, and are therefore not readily adaptable for detection; and

(3) Acoustic tests are a feasible means of tracing tunnel complexes from the ground surface.

It is recommended that further tests be performed to develop instrumentation and techniques of utilizing the acoustic method of tunnel tracing.

DYNAMIC TECHNIQUES FOR DETECTING AND TRACING TUNNEL COMPLEXES

Background, Purpose, and Scope

1. An investigation is currently being conducted by the Enginee Research and Development Laboratories (ERDL) for the purpose of determining methods of detecting tunnel networks. At the request of ERDL in a telephone conversation on 2 February 1966, between Mr. Z. B. Fry of the Waterways Experiment Station (WES) and Mr. Robert Kimble (ERDL), a field party was sent to a test site near Calhoun Falls, S. C. Tests were conducted during the period 11-13 February. The purpose of this investigation was to determine the feasibility of using various types of dynamic test techniques to detect and trace tunnel complexes.

Test Site Location and Conditions

2. The terrain in the vicinity of the tunnels was flat to slightly rolling with pine tree forests. The predominant soil in the area is red clay. During the testing there was continuous rainfall accompanied by occasional high winds.

Equipment and Measuring Techniques

Vibratory tests

3. Vibration tests were conducted to determine the length of surface (Rayleigh) waves generated by a vibrator at controlled frequencies. When sustained vibrations are induced into a soil, concentric waves are propagated outward and downward from the source.

By measuring the wavelength (utilizing instrumentation and techniques described in WES Miscellaneous Paper No. 4-577, "A Procedure for Determining Elastic Moduli of Soils by Field Vibratory Techniques," dated June 1963) and knowing the frequency of vibration, the wave velocity can be calculated as follows:

$$v = \lambda f$$

where

v = wave velocity, LT^{-1}

λ = wavelength, L

f = frequency of vibrator, cycles T^{-1}

4. As an approximation, it can be said that surface waves emanating from a vibratory source propagate through a depth about equal to half the wavelength. In previous tests at several test sites, it was found that subsurface anomalies (pipelines, cavities, conduits, etc.) disrupted the regularity of measured half-wavelengths. It was anticipated that the vibratory technique could possibly be utilized as a detection device for underground cavities, viz., tunnels.

5. Tests were conducted at the site by placing a small (50 lb force) vibrator at several locations away from the tunnel and running traverses perpendicular and parallel to it as shown in fig. 1. Numerous frequencies were selected for the tests, but it was found that the lowest frequency which could be successfully used was 75 cps. This allowed a depth penetration of only 4.2 ft which was not sufficient for the tunnel detection. External construction noises at the site and lack of adequate vibrator power were the deterrent

factors in a more complete investigation of the tunnel complex. Unfortunately, the large vibrator used for deeper investigations was not available at the time of field tests. It is surmised, however, that the vibratory method shows promise for detection of subsurface anomalies and further investigations should be conducted.

Drop hammer tests

6. Drop hammer tests were conducted on the basis of investigations performed by the U. S. Geological Survey on deep underground cavity detection. Results of tests conducted by USGS indicated that a sizable amplitude increase could be noted on geophones spaced immediately above a large cavity when excited by an explosive charge of large magnitude a considerable distance away from the detectors. This phenomena is thought to be caused by reverbration of the cavity, which is a closed volume, at its natural frequency. Tests were conducted by first locating the drop hammer (a 10-lb guided mass striking a 7-in. steel plate from a height of 5 ft) 25 ft from the center of the tunnel and a geophone 5 ft from the hammer on a perpendicular line toward the tunnel as shown in the test layout (fig. 1). The hammer was dropped from a height of 5 ft and the output of the geophone recorded on an oscillograph. The geophone was then moved in 5 ft increments toward the tunnel and recordings were made at each location for a distance of 25 ft, thus passing immediately above and a distance beyond the cavity. The hammer location was then moved toward the tunnel a distance of 5 ft and the same procedure was followed. Amplitudes were recorded from

hammer stations progressively up to 2 ft from the edge of the tunnel. These 25 recordings did not reveal any indication of an existing underground anomaly. A normal exponential amplitude decay pattern was exhibited by each progressive line. Test results therefore indicated that such a simplified method of detection was not feasible, probably due to a lack of adequate shock wave energy to resonate the underground chamber.

Seismic tests

7. Seismic tests were made to determine the compression wave velocity of the soils near the tunnel complex. These data were collected with a portable hammer-type seismic unit which incorporates a binary counter to measure elapsed time from the point of hammer impact to a single geophone receiver. These tests were performed, not for detection purposes, but merely for information on wave propagation characteristics of the soils at the test site. It was found that reliable impulses could be obtained from a sledge hammer blow for a horizontal distance of only 70 ft and associated compression wave velocities were approximately 2500 ft/sec for an undetermined depth estimated to be about 25 ft below ground surface. This depth was estimated by "rule of thumb" which is generally accepted to predict depth of wave propagation as equal to about 1/3 the total horizontal traverse distance.

Acoustic tests

8. Acoustic tests were performed to determine the feasibility of tracing an underground tunnel complex. A block diagram of the

instrumentation sending and receiving apparatus is shown in fig. 2. From this diagram it can be seen that an acoustic transducer (an acoustic suspension high fidelity loudspeaker system) was placed in one of the entrances to the tunnel complex and its resultant signal was received via acoustic coupling at the ground surface level by a moving coil velocity-type pickup. Tests were conducted by placing the pickup at a point known to be immediately above a section of the tunnel near the loudspeaker. The oscillator was swept through a wide range of frequencies and a frequency was selected where the amplitude of ground motion at the pickup was at a maximum level. The pickup was then moved to various locations both over the tunnel and away from the complex. Recordings were taken at each location and a frequency check was made. If it was found that another frequency resulted in a higher amplitude at a particular location, then a recording was also made at that frequency. This pattern was followed for two separate tunnel conditions: (a) shoring in place, and (b) shoring removed. These test layouts are shown respectively in figs. 3 and 4. Directions will be indicated as either right, left, up or down the referenced figure.

9. The initial data point taken in each test case was located in line with the speaker at the first "T" of the center tunnel in the complex. A frequency was selected at this point where the amplitude was at its maximum. During the tests with the shoring in place, the maximum amplitude at the "T" was obtained at 75 cps (fig. 3). As the pickup was moved outward (down the figure) from that point

the amplitude diminished from 6.7 to 0.9 in a distance of 9 ft. In moving either right or left along a line directly over the tunnel the amplitude dimished rapidly at a frequency of 75 cps; however, a frequency of 50 cps produced a larger amplitude. At a frequency of 50 cps the pickup was moved outward (down) at a point 12 ft to the right of the "T" and the amplitude diminished. However, as the pickup was moved in the opposite direction (upward) the amplitude progressively increased. As the pickup was moved further to the right from the "T" the maximum amplitude was produced at a frequency of 66 cps which was also the frequency producing the maximum amplitude at the corner to the right entrance shaft. The amplitude also increased as the pickup was moved upward between the center and right entrances for the 66 cps frequency and is attributed to the energy transfer resonating between the two tunnels. In moving the pickup to the left of the "T" the maximum amplitude was obtained at 57 cps at the first corner and progressively increased as the pickup was moved outward (down) from the corner for no apparent reason. A maximum amplitude was obtained at the left shaft at a frequency of 73 cps.

10. Tests conducted after the shoring was removed showed a noticeable decrease in frequency at which maximum amplitudes were observed. The same general trends were widened as found with shoring in place. The pickup was located initially at the "T" of the central tunnel entrance and a frequency of 44 cps produced the maximum amplitude (fig. 4). The amplitude decreased as the pickup was moved

outward (down) from the tunnel, although not as rapidly as when the shoring was installed. In moving right or left from the "T", first corner to left and midway between central and left entrance tunnels, the frequency producing the maximum amplitude was 66 cps. At the corner to the right shaft entrance the frequency producing maximum amplitude decreased to 51 cps. In moving outward from the tunnel at those frequencies there was only negligible decrease in amplitude. In moving further around the corner and along the tunnel to the left of the central tunnel the frequency producing the maximum amplitude was near 51 cps. One notable point of interest was the manner in which amplitudes at a frequency of 51 cps decreased, increased, and again decreased while moving from the tunnel "dogleg" toward the lower left of fig. 4. Tunnel geometry could possibly account for this irregularity. At each point where measurements were made, the frequency indicated on the figures produced the largest amplitude on the surface.

11. During the performance of tests with shoring in place, the speaker system was inadvertently turned over face down, thus transmitting a goodly portion of acoustic energy directly into the soil material. However, these amplitudes and frequencies are still shown for information and comparative purposes.

Conclusions and Recommendations

12. As a result of several dynamic test methods used for a feasibility study in the detection and tracing of underground tunnel

complexes it was concluded that:

a. Vibratory tests with a low power source were inconclusive for detection purposes.

b. Drop hammer tests did not release enough energy to cause reverbration of an underground cavity, and are therefore not readily adaptable for detection.

c. Acoustic tests are a feasible means of tracing tunnel complexes from the ground surface.

13. It is recommended that further tests be performed to develop instrumentation and techniques of utilizing the acoustic method of tunnel tracing.

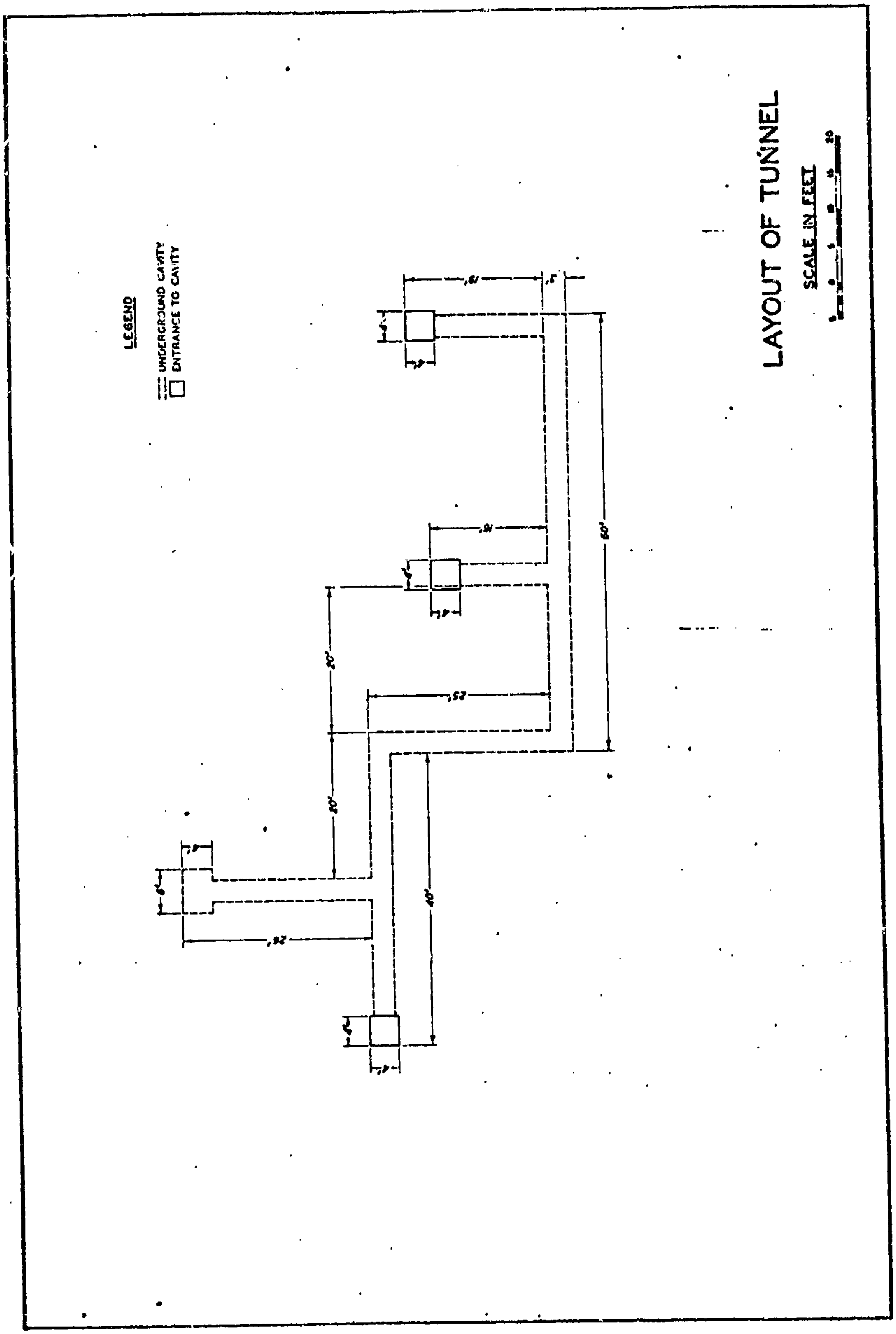

LAYOUT OF TUNNEL
SCALE IN FEET
LEGEND
UNDERGROUND CAVITY
ENTRANCE TO CAVITY

Fig. 1

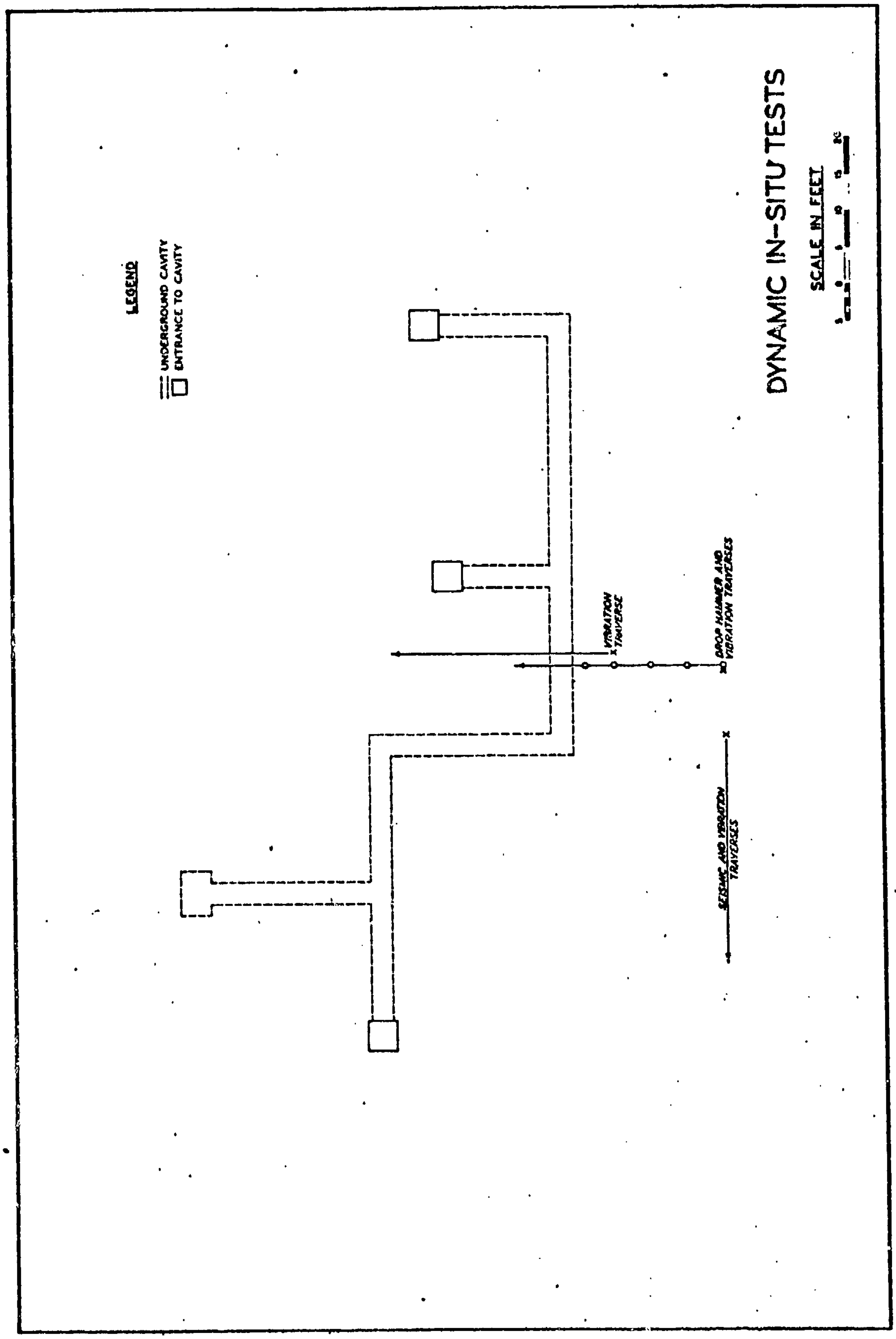
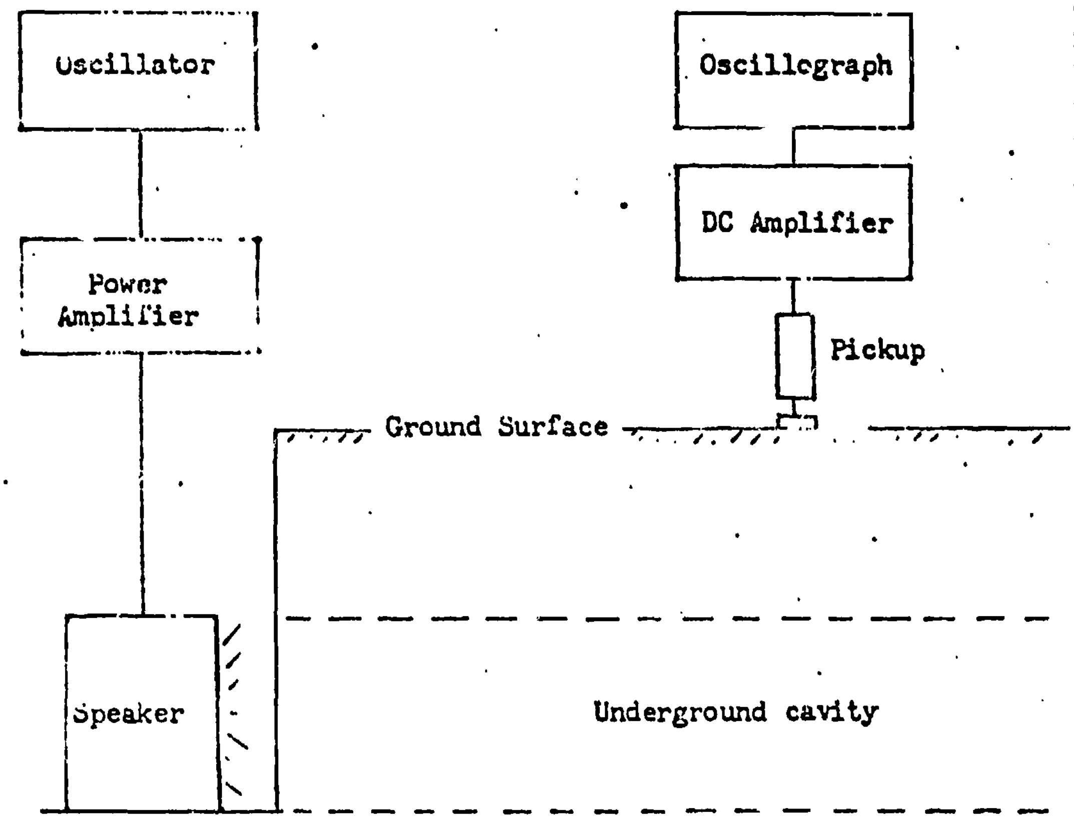

DYNAMIC IN-SITU TESTS
SCALE IN FEET
LEGEND
UNDERGROUND CAVITY
ENTRANCE TO CAVITY
VIBRATION TRAVERSE
DROP HAMMER AND VIBRATION TRAVERSES
SEISMIC AND VIBRATION TRAVERSES

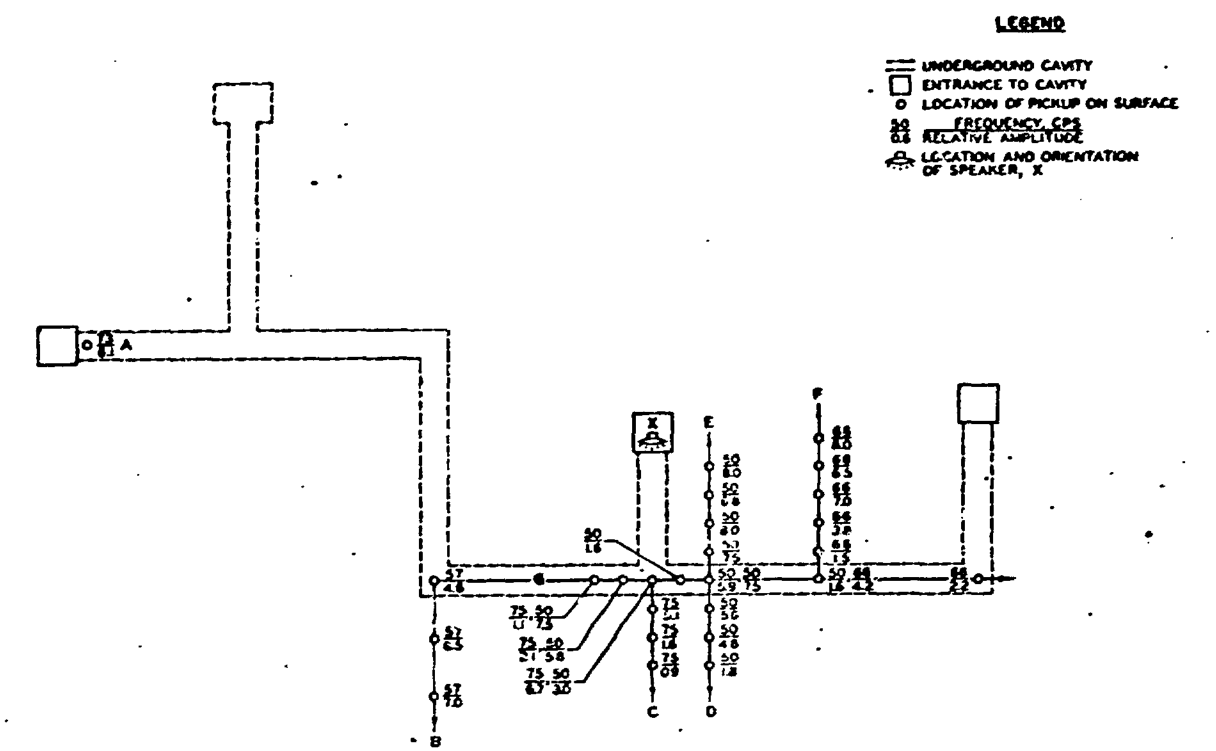
Fig. 2



Item	Make and Model
Signal Source System	
Oscillator	Hewlett-Packard 202 CR
Amplifier	Dynakit MK III 60 watt
Speaker	Acoustic Suspension System AR-3 30-20,000 cps
Signal Reception System	
Moving coil velocity-type pickup	Philips PR 9260 Sensitivity 0.7 v/in/sec or Hall Sears HS-10-1 Sensitivity 45 v/in/sec
Amplifier	Alinco 518
Oscillograph	CEC 5-124 + CEC 7-363 galvanometer

Block Diagram and
Associated Electronic Equipment

Fig. 3



TEST LAYOUT NO. 1
SHORING IN PLACE
11-12 FEB. 66
SCALE IN FEET

Fig.

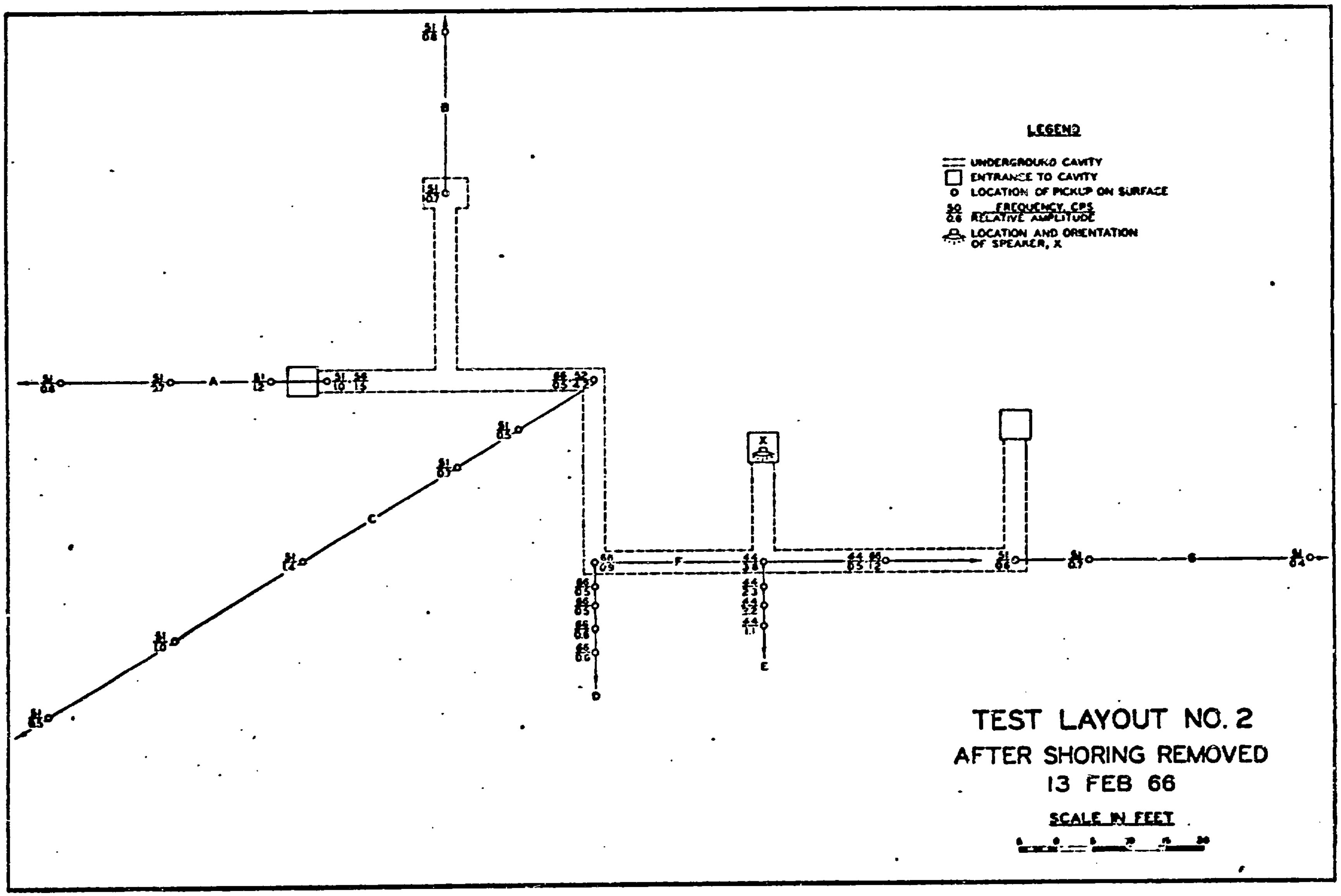

LEGEND
UNDERGROUND CAVITY
ENTRANCE TO CAVITY
LOCATION OF PICKUP ON SURFACE
FREQUENCY, CPS
RELATIVE AMPLITUDE
LOCATION AND ORIENTATION OF SPEAKER, X
A
B
C
D
E
F
X
TEST LAYOUT NO. 2
AFTER SHORING REMOVED
13 FEB 66
SCALE IN FEET

Fig. 5

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

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